A Moderate Energy, High Repetition Rate Marx Generator System for Pulse Charging Wide Band Antenna Structures

J. R. Mayes, E. Eubank, M Lara and M. G. Mayes
Applied Physical Electronics, L.C.
Austin, Texas 78734

J. Tatoian
Eureka Aerospace
Pasadena, CA 91107

Abstract

An ultra compact Marx generator system is fabricated for driving a wideband antenna structure with high repetition rates. The generator is designed to deliver 100 J per pulse, with an erected voltage of 640 kV. The generator employs an inductive element charging topology, which allows the 16 stages to be rapidly charged to a maximum voltage of 40 kV. The generator also integrates a 10 kW rapid capacitor charging power supply, which compactly mates to the end of the Marx generator. Design considerations are presented, as well as experimental results.

I. INTRODUCTION

Compact Marx generators have been employed for many years as trigger generators for larger systems and intermediate sources for high voltage pulses designed to pulse-charge pulse-forming lines. These generators are typically designed with pulse characteristics of more than 200 kV in peak voltage, 3 – 4 ns rise times, 1 – 3 ns rms jitter and pulse widths of 10's of ns. However, these systems grow in volume with increases in their erected voltages, since more Marx stages leads to higher source impedances and lower load voltage efficiencies.

However, recent efforts [1] with compact Marx generators have brought faster rise times, higher peak voltages, and increased load voltage efficiencies, making them good candidates for direct RF generation and indirect RF generation.

This paper discusses a compact Marx generator developed by Applied Physical Electronics, L.C. (APELC). The generator compactly adds 16 stages of three ceramic doorknob capacitors in a modular geometry for an erected voltage of up to 640 kV. This generator has been specifically designed for pulse charging ring down antenna structures, as being developed by Eureka Areospace. A 10 kW rapid capacitor charging, high voltage power supply is mated to the Marx generator. The power supply works from a 300 Vdc source voltage and pulse charges the Marx generator with voltages up to 40 kV, at 100 J per pulse and repetition rates up to 100 Hz. The trigger unit remains external. The generator system has been tested for impedance and high voltage operation. The results of this testing are presented.

II. Background and Design

A. The Wave Erection Marx Generator

Traditional and antiquated Marx generator designs simply fabricate the circuit based on the fundamental Marx circuit concept—i.e. charging a bank of parallel capacitors via resistors and then switching the capacitors into a series configuration via interconnecting spark gap switches for a voltage multiplication. This simple design leads to slow voltage rise times and relatively low load voltage efficiencies.

Newer design methodologies include a suitable ground plane and the consideration of the associated stray components. As shown in Figure 1, the complete Marx generator model with a ground plane includes the stray-to-ground capacitance at each stage, the series inductance due conductive materials and the switch physics, and the stage-to-stage capacitance. Designing the stray elements into the overall design can lead to a "wave erection", in which an electromagnetic wave efficiently propagates the Marx circuit as the switches sequentially close. As a result, ultra fast rise times and high load voltage efficiencies can result. [2]

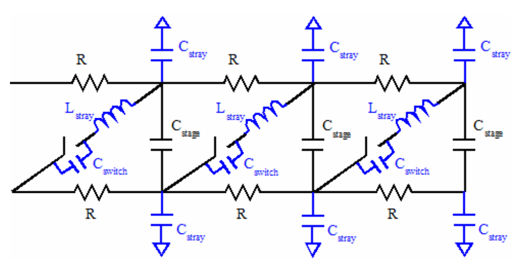

Figure 1. A schematic of the Marx generator considering the stray components.

B. Moderate Pulse Generator Design

The geometry the Marx generator is a sub-set design of APELC's successfully developed MV generator[1], using 16 of the 40 stages and modifying the output section for the lower peak voltage. The application ultimately requires a fully integrated design, incorporating the high voltage power supply and the trigger unit.

The completed design employs three TDK UHV-6A (30 kV, 2.7 nF) capacitors per stage, for a stage capacitance of 8.1 nF. The capacitors are mounted to an ABS insulator that also fixes the brass electrodes and provides electrical interconnects. The Marx stages, once integrated, compactly slide inside the insulating medium, which is fabricated with nylon. The liner has an internal diameter of 5 ½ inches and an outside diameter of 7 ½ inches. The liner is encased in an aluminum tube that has a wall thickness of ¼ inches. The completed generator has a length of 42 inches, with a tube diameter of 8 inches (a collar diameter of 9.5 inches). A conceptual view of the housing is shown in Figure 2.

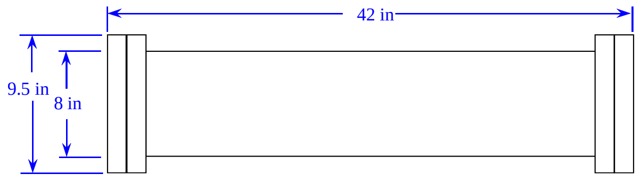

Figure 2. Cross-sectional conceptual view.

The 16-stage generator has been designed for delivering an erected voltage of 640 kV, with a pulse energy of 100 J. The generator has also been designed for operating with high repetition rates. The charging resistors were replaced with 10 μH inductors, and the pressurized air flows beneath each of the spark gap switches for purging particulate between shots. The flow rate is regulated by a purge valve located in the bulkhead of the Marx housing.

As described by Table 1, the generator is designed for a low impedance of 23 Ohms, a maximum peak power of 4.45 GW and a maximum repetition rate of 100 Hz, leading to an average power of 10 kW. Note that the repetition rate is power supply specific. The mechanical features of the generator are described by Table 2.

Table 1. Electrical characteristics of the generator.

Parameter	Description	Value	Unit
V_{open}	Open circuit voltage	640	kV
V_{ch}	Maximum charge voltage	40	kV
N	Number of stages	16	
N_{cap}	Number of capacitors per stage	3	
C_{stage}	Stage capacitance	8.1	nF
C_{marx}	Erected capacitance	500	pF
L_{marx}	Ereced series inductance	260	nH
Z_{marx}	Marx impedance	23	Ohms
V_{load}	Voltage on a matched load	320	kV
P_{peak}	Peak power	4.45	GW
E_{marx}	Energy stored in Marx	100	J
T_{ch}	Time to charge	6	ms
T_{RR}	Maximum repetition rate	100	Hz
P_{ave}	Average power	10	kW

Table 2. Physical characteristics of the generator.

Parameter	Description	Value	Unit
D	Diameter	8.5	in
L	Length	42	in
Wt	Weight	75	lbs

C. Power Supply Integration

New to APELC's Marx generator development efforts is the integration of Texas Tech University's Rapid Capacitor Charger power supply.[3] This charger has been designed for compactness, while delivering a charge voltage from 10 – 40 kV, at 100 J per charge and operating with repetition rates of up to 100 Hz. The power supply operates from a prime source of 300 Vdc, and is controlled from a separate, fiber optically connected control unit. Figure 3 provides a photograph of the charger and controller.

Figure 3. Photograph of the Rapid Capacitor Charger and controller.

The charger employs a Freescale 9S12 processor to coordinate two channels of Pulsed-width Modulated (PWM) signaling, driving the gates of an IGBT-switched H-Bridge. The processor of the 9S12 runs at 24 MHz, allowing ample duty-cycle resolution at a switching frequency of 30 kHz

C. System Overview

The complete system is illustrated in Figure 4, and includes the 16-stage Marx generator, the integrated power supply, an external thyratron-based trigger unit and the fiber-optically connected controller. The system requires a pressurized dry air source and a 300 Vdc, 10 kW electrical service.

A thyratron-based trigger source was chosen for its reliability and robustness to the harsh electric environment, and serves well for the demonstration effort. The unit has been designed for delivering a 1 J, 18 kV pulse, with a pulse repetition rate of 100 Hz. This unit is powered by a 120 V ac source. Ultimately, a solid state trigger unit will be integrated into the power supply section to complete the compact package.

The controller currently requires external programming, defining the capacitance of the generator, as well as the desired charge rate.

Operationally, the user must manually initialize the pressure setting, including the purge rate from the Marx generator housing. The user is then able to operate the system via the hand held controller, with command over the charge voltage of the generator and the number of shots in a burst. The controller command charges the Marx generator and initiates the trigger pulse.

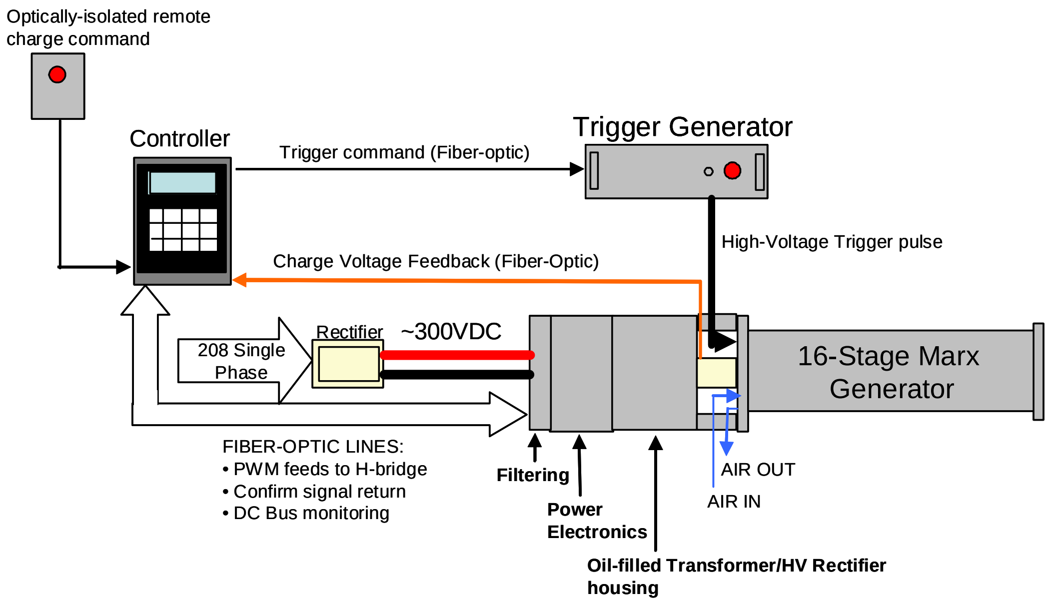

Figure 4. System view including the Marx generator, integrated power supply and external trigger unit.

IV. EXPERIMENTAL RESULTS

The completed Marx generator system is tested for its electrical characteristics with a resistive 15 Ohm load, before being ultimately tested with a matched capacitive load representing a portion of the antenna system developed by Eureka Aerospace.

Initial testing of the generator is done with a resistive load, submersed in an oil tank and terminated into a T&M Research Current Viewing Resistor (CVR). With this test arrangement, the Marx generator performance may be assessed over a wide variety of load impedances and with repetition rates from single shot to 100 Hz.

The first test performs a ringdown measurement designed to determine the generator's characteristic impedance. The load resistor is replaced with a shorting, conductive rod. The CVR monitors the ringdown, which is digitized by a TEK TDS 6604, 6 GHz realtime oscilloscope. The captured waveform is shown in Figure 5, a ringdown frequency of 4.6 MHz is measured. With a calculated load inductance of 2 μH removed from the overall inductance, a source inductance of 267 nH, is calculated and gives a source impedance of 23 Ohms.

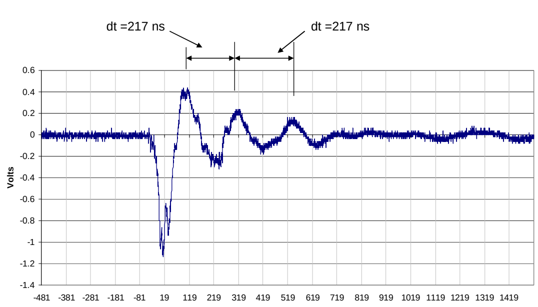

Figure 5. The CVR-based impedance measurement.

The rapid capacitor charger is also tested for its ability to charge the Marx generator. As expected, the power supply was able to charge the generator with a 40 kV voltage, at repetition rates of up to 100 Hz. During the testing phase, a wide variety of test voltages and repetition rates were used. Figure 6 provides a photograph of the charger controller with the resulting charging waveform on a 20 kV, 100 Hz shot.

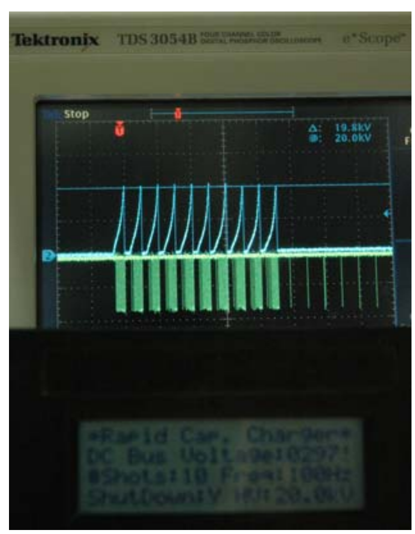

Figure 6. A photograph of the rapid charger control display and the resulting oscilloscope trace.

The Marx generator system was delivered to Eureka Aerospace for testing with the antenna system. Although the antenna system is not discussed in this text, the load appears to the Marx generator as a matched capacitive load of 500 pF. Several calibrated D-dot probes are placed in the capacitor load, as well as current monitors.

Figure 7 provides a sample of the raw data, as well as an integrated data as measured by the capacitive probes. The integrated waveform shows that the generator successfully pulse-charges the capacitor in less than 6 ns. Once the capacitor has been charged, the energy is dumped into the antenna geometry, where it is ultimately radiated.

V. CONCLUSION

This paper has presented preliminary results of a compact Marx generator that has been specifically designed for pulse charing wide band antenna elements. This effort successfully integrates a rapid capacitor-charging high voltage power supply, but employs an external trigger unit.

The Marx generator has been shown to have a source impedance of 23 Ohms, which was measured using a short-circuited ringdown measurement and a T&M Research Products CVR. The power supply was tested for its ability to charge the Marx generator to a charge voltage of 40 kV, and repetition rates of up to 100 Hz. Ultimately, the Marx generator system was tested with the antenna geometry designed and fabricated by Eureka Aerospace. This arrangement has the APELC Marx generator pulse charging a 500 pF transfer capacitor, that matches the erected capacitance of the generator.

VI. REFERENCES

1. A Compact MV Marx Generator, J.R. Mayes, Conference Record of the Twenty-Sixth International Power Modulator Conference, San Francisco, 2004
2. D. Platts, GigaWatt Marx Bank Pulsers, Ultra-Wideband Radar: Proceedings of the First Los Alamos Symposium, Ed. Bruce Noel, CRC Press, 1991
3. Rapid Capacitor Charger for 10 Hz Operation of a Low-Inductance Compact Marx Generator, M. Giesselmann, Brent McHale and Andreas Neuber, Conference Record of the 27th International Power Modulator Conference, Washington, D.C., May 14 – 18, 2006.

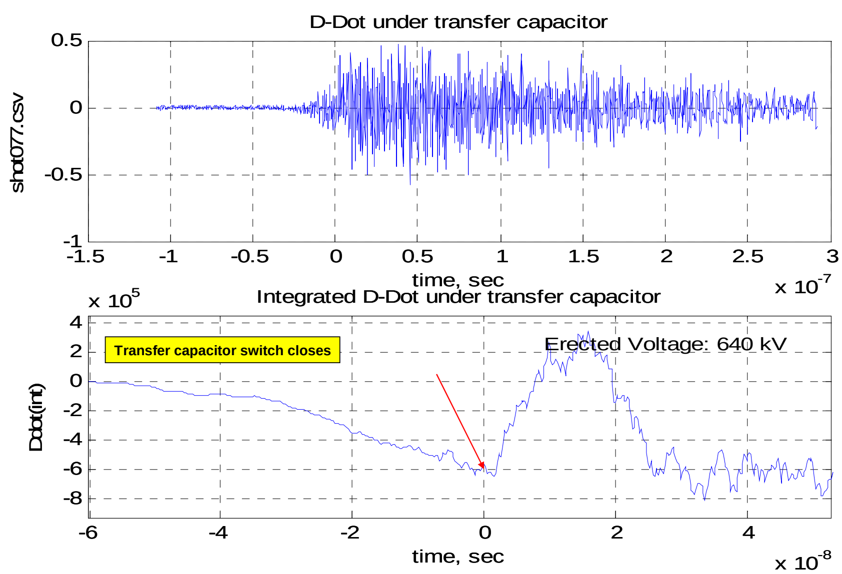

Figure 7. Output waveform with a 30 kV charge.